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JAMES DWIGHT DANA AND HIS WORK AS A GEOLOGIST.

JAMES DWIGHT DANA, who for a generation has been our foremost geologist, on the fourteenth day of last April, died at the ripe age of eighty-two years. It is difficult to appreciate how much American geologists owe to the indefatigable industry of this one man; though he has laid down his pen, the results of his labors remain with us, and are wrought into the very foundation structure of American geology. The main events of his busy life have been narrated in many places; one of the most vivid sketches is the one published in the *American Journal of Science*, written by his son. To this we would refer for a clear view of the many-sided life as a whole.

There were certain conditions of birth and early education — certain traits of character — and events in his early life, which in some measure specially prepared him for the career which he so successfully carried out. A few of these may be here recounted as an introduction to this brief sketch of his work as a geologist.

Dana was the son of an active, successful business man; and the qualities of business common sense, industry and economy thus acquired, although he chose to apply them in other than commercial pursuits, were elements of inheritance which contributed greatly to the quality of his greatness and success.

In his boyhood he had the stimulation of a great teacher,

whose enthusiasm for natural history tempered by a thorough English culture and education, stirred in him the appetite for investigation and the reverence for the truth, which never left him, but grew with his growth and became the dominating qualities of his character.

Having determined to devote his life to the study and interpretation of nature he chose the most direct ways of fitting himself for the work. He felt the importance of a liberal college education, and entered the Class of 1833 in Yale college, where Silliman was making himself and the college famous for the teaching and encouragement of science. With Silliman he became a devoted pupil of mineralogy, chemistry and geology, but particularly of the first. Silliman's public lecturing began while Dana was in college, and the course of lectures in Hartford in 1834, and the Lowell lectures in Boston in 1835, were the beginning of awakening of the public interest in science throughout America.

Comparing him with others, the influence of this liberal education is seen throughout his writings, in the remarkably philosophical grasp, in the deep insight with which every subject of his investigation was handled, and in the breadth of his interests and his thorough appreciation of the true proportions and relations of things to each other.

He also had the extraordinary advantages of wide travel, which particularly fitted him to be an interpreter of the grander problems of geology, to which in the latter half of his life he gave chief attention. Immediately after graduation he took a cruise on the U. S. Frigates "Delaware" and "United States," across the Atlantic and about the Mediterranean, in the capacity of teacher of mathematics to the midshipmen, but learning and observing meanwhile, studying mineralogy and crystallography inside his cabin, and seeing whatever he could see on sea and land outside. His first scientific paper was written from the U. S. Frigate "United States," in 1834, "On the condition of Vesuvius in July 1834."[1]

[1] See American Journ. Sci. (1) Vol. XXVII., pp. 281–288.

The other and chief voyage was with the United States exploring expedition under Commodore Wilkes, which sailed in August 1838 and reached New York on the return in June 1842. The route took him through the Southern Atlantic, the Straits of Magellan, up the western coast of South America, among the islands of the Pacific, to the western coast of North America, where he was shipwrecked and went overland from the mouth of the Columbia River through Oregon, across the flank of Mt. Shasta and through north California to San Francisco, thence across the Pacific again to the Sandwich Islands, Singapore and around the Cape of Good Hope into the Southern Pacific and thence home to New York.

In this long cruise he acted in the capacity of geologist and mineralogist, but by the failure of others to fill their places, he ultimately became the observer and reporter on all the natural history. The official reports he wrote were three: the first, "On Zoöphytes," 741 pages with a folio atlas of 61 plates, was published in 1846; the second, "On Geology," 756 pages, with a folio atlas of 21 plates, was issued in 1849. The third was "On the Crustacea," in two parts, with a total of 1620 pages and 96 folio plates, and was issued in 1854. A large number of lesser papers and treatises were founded upon facts accumulated during this voyage, or upon investigations carried on in elaborating those observations.

Three lines of investigations, which continued to occupy his attention more or less to the end of his life, were the direct outcome of the experiences of this voyage; these were about 1) Corals and Coral Islands, 2) Volcanoes and the associated problems of mountain making and continental development, and 3) Cephalization; the last topic being incident to the studies made in preparation of the report "On Crustacea." In each of these problems he took keen interest and contributed greatly to their elucidation. His interest in volcanoes led him to make a journey to the Sandwich Islands in the latter part of his life (1887) to see for himself the changes that had taken place, and to compare Kilauea and other volcanoes of Hawaii as they had become, with their condition as observed by him in 1840. As a result of these new

studies he wrote "Characteristics of Volcanoes, with contributions of facts and principles from the Hawaiian Islands," 400 pages, in 1890. Much might be said in elaboration of this subject, — the influence of the experiences of 1838–42 in shaping his future investigations and contributions to science — and some of the developments of his geological theories and works will be briefly traced beyond; but space will not here admit the discussion of the equally interesting contributions Dana made to the subject of organic evolution and the correlations between the conditions of life, geological time, and the structure and form of organisms. His studies in the several fields of organisms, minerals and geology made in the earlier, most active period of his life (if there was any time in his life when his activity was abated except by sickness) were an important factor in enabling him to understand nature intimately in her more hidden workings, which by most observers is seen from only one side and therefore but partially comprehended. After returning from the exploring expedition, he spent two years at Washington working on the reports, then he went to New Haven where he resided throughout the remainder of his life.

In the interval between the first two ocean voyages, he was Professor Silliman's Assistant in Yale college, and then produced his first important work, *A System of Mineralogy: including an extended treatise of crystallography with an appendix containing the application of mathematics to crystallographic investigation, and a mineralogical bibliography.* The first edition was of 594 pages and was published in 1837. The title though long gives a concise description of the scope of this book which at once took a first place as a treatise on mineralogy in the English language, and in its successive editions it has not lost its place up to the present day.

That geology was his favorite study is shown by the number of titles in the bibliography. Dividing the list by decades, beginning with 1835, for the first three decades the number of titles is almost equally distributed in the three groups: Geology 37, Mineralogy 34, Zoölogy 38. After 1865, however, but seven

papers are strictly mineralogical, and but five were devoted to zoölogy, while of geological papers and books, there are nineteen between '65 and '75, thirty-three between '75–'85, and in the last decade of his life thirty-one, making a total of 120 titles in the geological list, an average of two per year for the whole period of sixty years of his literary activity.

Mineralogy, which first attracted his interest, was early perfected into a system, and after the time of his taking the professorship in Yale college he wrote few special papers on mineralogy, and thereafter turned his attention more and more to geological studies. The 4th edition of the *System of Mineralogy* appeared in 1854 with the fully perfected chemical classification. The 5th edition, which included the complete systematic description of known mineral species, was prepared with the assistance of Professor G. J. Brush, and in the preparation of the 6th edition by his son Edward S. Dana, he was unable to take an active part.

His chief zoölogical works were the reports "On Zoöphytes" and "On Crustacea" of the Wilke's exploring expedition; the former was published in 1846, the latter in 1854. A considerable number of papers were written "On Cephalization," in which he was deeply interested up to about 1866, after that date he produced scarcely anything of purely zoölogical nature.

Geology is a much more complex and miscellaneous science than either mineralogy or zoölogy, and therefore it is difficult to so arrange the facts as to exhibit their relation to any single common principle. But we believe Dana's *Manual* has come nearer to the setting forth of such an ideal system of geology than has been elsewhere attained. The central ideas in this system are: (*a*) the earth a cooling globe,—(*b*) contracting as it cools,—(*c*) differences of depression and elevation of the surface the direct result of the unequal contracting,—(*d*) oceans and continents permanent,— (*e*) trends of shores, of islands and mountains, according to system, and expressive of lines of weakness, and of chief foldings and fractures, (*f*) epeirogenic and orogenic phenomena the direct results of the contracting,—(*g*) climates and currents of the ocean also the effects of changes

in elevation of the continents, — (*h*) the separation of the history of the earth into ages by the revolutions at the climaxes in the contraction, when strain and tension came to exceed strength and resistance, and resulted in folding and faulting and local disturbances, and were marked by the greater or less extermination of life, followed by repeopling by, and the modification of the successors, — (*i*) the surface shaping of the continents by ice and water action also influenced by oscillation of level of the continents; and all of these various factors taking a part in producing the present complex condition of the earth's surface.

The earth as a whole was the unit which was before his mind as he constructed this system of geology. As he traced its history he saw in the successive events of geology the marks of the gradual development of a vaporous, then incandescent, and finally hardened, contracting, cooling globe. Others had spoken of geology as a history; but he appears to have been the first to write a manual of geology in English based on this idea. "In history," he commented, "the phases of every age are deeply rooted in the preceding, and intimately dependent on the whole past. There is a literal unfolding of events as time moves on, and this is eminently true of geology." Hence he began his geology with the beginnings, and followed the course of the history of the earth onward.

Again, to Dana the means of measuring the sequence of events was the succession of fossils. "Geology is not simply the science of rocks, for rocks are but incidents in the earth's history, and may or may not have been the same in distant places. It has its more exalted end, — even the study of the progress of life from its earliest dawn to the appearance of man; and instead of saying that fossils are of use to determine rocks, we should rather say that the rocks are of use for the display of the succession of fossils. Both statements are correct; but the latter is the fundamental truth in the science." It was this idea which dominated in his classification of geological formations.

American geologists are all aware that it is from the use of Dana's system that the habit of speaking of geological Periods

and Epochs has been acquired. Other manuals speak of formations, systems and étages, of series and groups; rocks being classified as if they were distinguished by some qualities of their own. It is from Dana that we have learned to classify geological formations in relation to the stages of progress in the building of the continents and its local structural features, and to regard rocks as not simply aggregates of mineral matter, but as geological formations bearing a definite relationship to the progress in the history of the earth, and hence as belonging to, and to be defined as of a particular period or epoch. In the first edition of his *Manual* in 1862 the author wrote:

"It has been the author's aim to present for study, not a series of rocks with their dead fossils, but the successive phases in the history of the earth,—its continents, seas, climates, life and the various operations of progress."[1]

The grand outlines of Dana's system of the earth's development are given in a few sentences in his article "On the Plan of Development in the Geological History of North America," first published in the *American Journal of Science* in 1856.[2]

"What then is the principle," he wrote, "of development through which these grand results in the earth's structure and features have been brought about? We detect a plan of progress in the developing germ; we trace out the spot which is first defined, and thence follow the evolution in different lines to the completed result: may we similarly search out the philosophy of the earth's progress? The organizing agencies in the sphere are, 1) Chemical combination and crystallization. 2) Heat, in vaporization, fusion and expansion, with the correlate force of contraction which has been in increasing action from the time the globe began to be a cooling globe. 3) The external physical agencies, preëminently water and the atmosphere, chiseling and

[1] Manual of Geology: treating of the principles of the science with special reference to American Geological History, for the use of colleges, academies and schools of science, by JAMES D. DANA, pp. xvi. + 798, illustrated by a chart of the world, and over one thousand figures, mostly from American sources: Philadelphia and London, 1863.

[2] Am. Journ. Sci. II., Vol. XXII., p. 339.

moulding the surface. 4) The superadded agency of life. Of these causes, the first is the molecular power by which the material of the crust has been prepared. The third and fourth have only worked over the exposed surface. But the second while molecular in origin, is mechanical in action, and in the way of contraction, especially, it has engaged the universal sphere, causing a shrinkage of its vast sides, a heaving and sinking in world-wide movements. Its action, therefore, has been coextensive with the earth's surface through the earth's history" (*loc. cit.* p. 340). On a later page a footnote again refers to this same dominant idea: "I have alluded on a former page to an analogy between the progress of the earth and that of a germ. In this there is nothing fanciful; for there is a general law, as is now known, at the basis of all development which is strikingly exhibited even in the earth's physical progress. The law, as it has been recognized, is simply this:—Unity evolving multiplicity of parts through successive individualizations proceeding from the more fundamental onward" (p. 346).

Notwithstanding all the additions of details and statistics in illustration and elaboration of this idea, we see, up to the last, this is the dominating principle about which his system of geology was built; and the American continent, as its geological features were gradually opened to light, was recognized as the most typical illustration of this system to be found upon the globe. In the last edition of the *Manual* we find these words: "North American geology is still its chief subject. . . . The idea long before recognized [*i. e.*, before 1855] that all observations on the rocks, however local, bore directly on the stages in the growth of the continent, derives universal importance from the recognition of North America as the world's type-continent—the only continent that gives, in a full and simple way, the fundamental principles of continental development."

He was not, however, carried away by theories, his scientific research was always deep, thorough and exact. As he was preparing the report on the geology of the exploring expedition he was not satisfied with simply describing what he saw. He

not only made a thorough study of the volcanoes in the islands of the Pacific and on the borders of the South American continent, and Vesuvius and Ætna in Italy (his first scientific paper as before noticed was a letter written from U. S. frigate "United States" in 1834 "On the condition of Vesuvius in July 1834"), but in his investigations of the many questions raised by these observations he also studied the surface of the moon,—and comparison of the already cooled moon and its extinct craters with the present condition of the earth suggested the chief phenomena about which was later elaborated his theory of the earth's development as a cooling, and necessarily contracting globe.

This paper, read before the Association of American Geologists and Scientists in September 1846, "On the Volcanoes of the Moon," suggested the following: "Thoughts bearing on our own planet." 1. If the earth was once a melted globe, it must have passed through the same phases as the moon, with this very important difference, that the whole surface during its progress was subject to the denuding action of waters and from the first had valleys and sedimentary rocks in progress. 2. Certain conclusions regarding the "origin of the mineral constitution of igneous rocks," including the idea that differences in fusibility will determine the mineral combinations, and that "the same igneous rocks may occur of all ages, etc." 3. As to origin of continents "the areas of the surface constituting the continents were first free from eruptive fires. These portions cooled first, and consequently the contraction in progress affected most the other parts. The great depressions occupied by the oceans thus began; and for a long period afterward, continued deepening by slow, though it may have been unequal progress." He cites the evidence of elevations all along the geological history, the presence of marine fossils in elevated upturned strata and the depression of the oceans in the coral islands, quoting the observations of Mr. Darwin, and referring to his own, to be reported on later, in confirmation of these views. The outline of the system is tersely expressed in the closing sentence of this article:

"The principles explained place the general theory of change of

level by contraction upon something better than a hypothetical basis, and are believed to explain the actual causes by which the changes have been produced. They correspond moreover with the view that ruptures, elevations, foldings and contortions of strata have been produced in the course of contraction. The greater subsidence of the oceanic parts would necessarily occasion that lateral pressure required for the rise and various foldings of the Alleghenies and like regions."[1]

The theory was further elaborated in the following year in three papers which appeared in the *American Journal of Science* "On the origin of Continents;"[2] "Geological results of the Earth's Contraction in consequence of cooling,"[3] and "Origin of the Grand Outline features of the Earth,"[4] and was finally put into systematic form in his *Manual of Geology*.

The general contraction theory was not original with Dana, as he acknowledged in these papers. He found it advocated by Leibnitz in 1691. Babbage and De le Beche had formulated the general theory of changes of level by contraction and expansion and the rise of continents. Mather, Elie de Beaumont, Lyell and others had made more or less reference to the principle, and M. Constant Provost had published in 1860 his view that the agency of contraction alone will account for the various changes of level which the continental areas have undergone. There were however certain features which were his own, as shown in the following passage:

"The reader will perceive that although the main principles of Provost are sustained by the writer in this and his former paper, the manner in which these principles are carried out, is in some respects a little different, especially in the idea that the oceanic areas have been the more igneous parts of the globe, and for this reason have contracted most; that certain orographic changes over the continents are due to contraction beneath the oceanic regions, and that the fissurings and mountain elevations have for this reason taken place in some instances near the margin of a continent, or near the limit between the great

[1] Am. Jour. Sci. II., Vol. II., p. 355.

[2] Am. Jour. Sci. II., Vol. III., p. 94.

[3] Loc. cit., p. 176.

[4] Loc. cit., p. 381.

contracting and non-contracting (comparatively non-contracting) areas. The efficiency of the cause of contraction has appeared to the writer to be wider and more evident, as the subject has received closer attention; and the study of it very naturally led to modifications of former views."[1]

Thus, it will be seen, that although others had before conceived of the idea of the general effects of contraction, it was to Dana the working hypothesis in the construction of a system of geology.

Although later investigations have added new light for the interpretation of the details of mountain building and earth shaping, a reference to the chief points of the theory, as elaborated by Dana in 1847 will show how much we are indebted to him for a clear exposition of the general principles of the science. In the second article "On Geological Results of the Earth's Contraction" these principles are stated. In regard to the Appalachian Chain, the general structure of which the Rogers brothers had already elaborated, the peculiarities were by them explained as the result of the propelling force or thrust of moving waves of molten material beneath, and the "disrupting tension of the compressed gaseous matter." Mather had previously spoken of the effects of refrigeration of the earth, but he found the cause of the features of the Appalachians in "a paroxysmal elevation and the action of inertia due to the more rapid westward motion of the part of crust lifted up further from the center of revolution." In the article above referred to, Dana wrote, "The principal peculiarity of these plications to which we would ask attention, is the following: the greater abruptness of the northwestern slope of each fold, in connection with the diminution of the undulations to the northwestward; and it will be our endeavor to show that this peculiarity, and the irregularities which exist are necessary results of the action of a force laterally exerted;" and he proceeded to demonstrate how by this power, "a series of folds would be produced each with the inclination steepest on the side farthest from A (the point of resistance); and moreover, these

[1] Am. Jour. Sci. II., Vol. III., p. 179, 1847.

folds would be necessarily most abrupt the nearer they are to A" (p. 184). Further on he gives four chief "reasons why this action should not produce perfectly regular and uniform folds: (1) from a variation in thickness of the bed; (2) from a want of uniformity in the material or its state of induration; (3) from an inequality in the action of the force upon different parts of the line against which it operates; (4) from irregularity in the contraction going on beneath the area." He observed a third principle, viz., that by the effect of gravity alone plication would be produced in much inclined or tilted clayey layers, while the sandy layers unless greatly indurated would settle bodily. A fourth principle is stated thus, "If the material subjected to lateral pressure be not capable of folding, or only partially so, the region operated upon instead of rising into a series of elevations would be raised into one or more ridges of much greater height." A fifth principle is that intruded igneous rocks or dikes may not be the cause, but are rather "a concomitant result of the same general operation." A sixth principle is "the folding of strata by subsidence of the plicated region can be only of small extent." Seventh, he says "the occurrence of volcanoes mostly in the neighborhood of the sea is a necessary result of these principles." The eighth principle is that the grander geological epochs are the direct result of more or less catastrophic periods which would separate, according to the theory, longer periods of comparative quiet, thus forming the transition breaks between the great systems.

While Dana was a consistent uniformitarian, in so far as to interpret past phenomena of the earth's history by the operations of forces such as are now in action, he clearly saw the natural relations of periods of special disturbance of the strata by the reaching of high degrees of tension and their expression in elevation and fractures along lines of tension, and the more quiet periods of chief sedimentation. This principle is better elaborated in the latest edition of the *Manual* than in previous works, on account of the fuller knowledge of the facts finally attained. In the development of the American continent there are recog-

nized, not only long periods of sedimentation and accumulation of strata in synclinoria, but separating these periods of quiet there were revolutions resulting in each case in lifting greater or smaller areas permanently above the surface of the ocean, and the later of these revolutions were the grander, in amount of elevations and mountain making, in fracturing and lava outflows, and in production of volcanoes, because, as his theory explains, of the greater thickness and rigidity of the crustal portion of the earth incident to the secular cooling of the globe.

In the article of 1847 the Appalachian revolution closing the Palæozoic, and what has been subsequently called the Palisade revolution, which terminated the Jura-Trias of the Atlantic border region, are distinctly referred to; and besides these we now know of the Taconic revolution, at the close of the lower Silurian; the Acadian revolution terminating the Devonian in the east; the great Rocky Mountain revolutions terminating the Mesozoic and bringing in the Tertiary conditions in the Laramide elevations, progressing a stage farther in the lifting of the Coast Range region at the close of the Miocene, and finishing its work at the close of Pliocene in the lifting of the Sierra Nevadas. That these more or less catastrophic events were the natural consequences of the continuous uniform cooling and contracting of the crustal portions of the globe, is a corollary of Dana's theory of the earth. As he observed, referring to these revolutions in the last edition of the *Manual*, "the above facts are brought forward to illustrate the grand principle, already admitted by some writers, that such grand crises,—by causing wide emissions of heat and changes of level in the sea, and violent shakings of the globe with its mobile waters,—were in early times a necessary result of the contraction in progress."

Referring to the Appalachian revolution, he wrote, "It is not a matter of surprise that there should have been an abrupt cessation with this event of preëxisting forms of marine life. The period when the effects of dislocation began to be transferred from the oceanic areas to the continents appears to have been the era of this catastrophe, and it was an era of similar changes

in various parts of the globe." The forty-eight years of constant study of the new discoveries in geology and testing the theory has shown it to be founded on fundamental truths of geology. The importance of this one, among the causes producing the changes which have taken place in the history of organisms, is a sufficient reason for here making a lengthy quotation from the fourth edition of the *Manual* regarding the application of this theory. Speaking of the disappearances of life at the close of the Palæozoic, the following is written:

"There was no break in the stream of life, but for the most part only seeming interruptions, and many of these owe their prominence in geological history to the culminations and declines of types that were in progress. But it was an epoch of relatively abrupt change, and if chiefly due to the progressive evolution of new species, as has been urged by some geologists, there must have been for the result a great acceleration in such change in consequence of the physical conditions produced by the orogenic disturbances. But the orogenic movements were local and the biologically transforming effects from such a cause should have been confined to the countries where these movements were in progress. The universality and abruptness of the disappearances cannot therefore be so explained. Very much is left for the destructive effects direct and indirect, that is, the exterminations attending the mountain making.

"The causes of the exterminations suggested by the changes are two: (1) A colder climate over the land, and colder waters in the extra-tropical oceans, for the emergence of the eastern semi-continent of North America and of large lands in the other continents could not fail to lower somewhat the temperature of the whole globe. With a lower temperature, the currents from the north sweeping along the coasts would have been destructive to the marine species living in the waters. (2) Earthquake waves produced by orogenic movements. If North America from the west of the Carolinas to the Mississippi Valley can be shaken in consequence of a little slip along a fracture in times of perfect quiet, and ruin mark its movements, incalculable violence and great surgings of the ocean should have occurred and been often repeated during the progress of the flexures, miles in height and space, and slips along newly opened fractures that kept up their interrupted progress through thousands of feet of displacement. The

Acadian upturning took place on the ocean border, and the Appalachian was not far distant from it, Arkansas, moreover, added to the extent of the belt of disturbance. Under such circumstances devastation of the sea border and the low lying land of the period, the destruction of their animals and plants, would have been a sure result. The survivors within a long distance of the coast line would have been few. The same waves would have swept over European land and seas, and there found coadjutors for new strife in earthquake waves of European origin. These times of catastrophe may have continued in America through half of the following Triassic period, for fully two-thirds of the Triassic period are represented by rocks and fossils on the Atlantic border" (p. 736).

Thus the course of the evolution of the life on its surface was in no small way dependent upon the gradual contracting of a cooling globe.

Not only did Dana take this broad and comprehensive view of the whole system of geological phenomena, but he made a thorough and particular study of several of the more difficult problems of American geology; among them may be named the interpretation of the glacial phenomena over New England and the classification of the period for North America—the solution of the "Taconic" controversy, and the associated questions of metamorphism and mountain building.

When the first edition of the *Manual* was issued (1863) there was far from unaniminity of opinion among American geologists as to the agency by which "drift" gravel and bowlders had been spread over the surface of the more northern states of the Union.

Dana interpreted the "drift" and the striations on the surface of the rock to be evidences of glaciation, and he was an earnest advocate of the theory of a great continental glacier, as opposed to the iceberg theory. Although few of the present generation have ever held another opinion, some of us will remember the strenuous defense of the iceberg theory so lately as the meeting of the American Association of Science at Montreal. Professor Dana not only opposed that theory from the beginning, but by his indefatigable personal studies of the surface topography and markings in the Connecticut Valley, and

particularly in and about New Haven, as well as with less minuteness, over much of New England and in parts of New York state, accumulated the evidence, which has not only thoroughly proven the glacial theory, but has furnished the greater part of the fundamental facts upon which is built the present classification of the glacial period as given in his *Manual*. To be sure, many other workers have furnished abundant contributions and have greatly elaborated these facts, but when we examine the literature and observe the part Dana took, in formulating the grand outlines as well as many of the particulars of our general theory of the glacial period in America, we find his part in laying the foundation of opinion was far greater than that of any other one man.

His papers in the *American Journal of Science*, beginning in 1863 and not ceasing till the year 1893, are numerous, and are based upon his personal observations in the field. They cover the discussion of each of the important questions which enter into the present theory of the glacial period. Such were: the directions of striæ and their relations to topography, with the establishment of the fact of their local deflection to follow the course of larger valleys, as the Mohawk, the Hudson Valley, the Connecticut River valley, etc.; the floods resulting from the melting of glaciers and the nature of evidence left by them; the absence of marine life in Long Island Sound through the glacial and part of the Champlain period; reindeer of Arctic type in southern New England; depression of land during the melting of the great glacier; damming of streams by ice; and Kames and their relations to the ordinary materials of drift. These, and many others of the particular phenomena of glaciation were built into the definition of the glacial period as he elaborated it from his personal observations.

Even to his last days his interest in the glacial question was keen and wide. In the preparation of the fourth edition of the *Manual*, although confined to New Haven, he made a thorough revision of the chapters on that subject. He realized that outside his quiet study hot controversies were going on among gla-

cialists of different opinions in America, and he took the greatest pains to get from original sources the evidence on both sides. He opened the pages of the *Journal of Science* to discussion of both views. His correspondence was widely extended, and with, I presume, every one of those who had taken a prominent part in the discussions of the past few years. In a conversation with the writer on one of those days, he remarked that one of the chief causes of contrary opinions regarding the division of the glacial period in America was, he believed, due to local coloring resulting from taking either the phenomena of New England and the eastern edge of the glacier, or else those of the western-central region, as the standards of judgment by the two sides in the discussions.

When he had finished the pages on the quaternary for the printers, he remarked that he had reached an explanation of the events which he thought would harmonize the divergent views, and he expressed more than ordinary enthusiasm, and spoke as if, having exhaustively compared all the facts that had been brought forward, he had reached what he believed to be the true solution of the vexing problem.

His explanation of the case, viz., an epoch of extreme advance, which was of great length, with, following, an epoch of first retreat, then halt, in which the deposits of the Lafayette formations were being made on the gulf and eastern borders, and with, third, the epoch of final retreat of the ice from the northeastern plateau, is certainly a comprehensive interpretation of the series of phenomena as a whole, however it may be modified by increasing knowledge. (See *Manual of Geology,* 4th ed., pp. 943–80.)

The clearing up of the confusion involved in Emmons' "Taconic System," was another task to which Professor Dana gave enthusiastic attention. After some thirty years of defense of the system by its friends, against the ineffective attacks of those who were unable to bring convincing proof of its fallacies, Professor Dana entered the field in 1871. The main trouble was that Emmons' interpretation was based upon several false tenets which were then maintained by the best of geologists; and it was

necessary to demonstrate their falsity before they could be laid aside. Prominent among them was the belief, that the age of a rock can be determined by its lithological characters. In the absence of fossils, the granular quartz was thus determined to be metamorphozed Potsdam Sandstone, and both Cambrian and Hudson River Slates were included under the name Taconic Slates, and supposed to be of pre-Cambrian age. A second error was the belief that the presence of certain minerals may be relied upon for identifying horizons—and a third point, which though known to be false, was too much trusted in even by those who knew better; viz., that actual succession of rocks in a metamorphozed region is a safe-guide in determining the order of sequence. In 1871 Professor Dana entered the field determined to settle the disputed questions by study of the region itself. "My purpose," he wrote, "was (1) to prove the continuity from north to south of the three associated Taconic formations, the quartzite, the limestone and the slates or schists; also (2) to work out the system of flexures; (3) to ascertain whether the Taconic mountains were generally or not of synclinal structure, as they were made by Rogers, Mather and Hall, and in 1864 by Logan; (4) to settle the question as to continuity from east to west of the limestones of the different north-and-south belts; (5) to apply the evidence from fossils, making them the sole basis for fixing the age of the beds; and finally (6) to use the evidence of the age, thus obtained, for the determination of the age of the hydromica schists, chloritic schists, garnetiferous and staurolitic schists, and other rocks of the Taconic Mountains, and thus test the value of, or give greater precision to, the assumed 'lithological canon' first propounded by Emmons. My work was continued in western New England and eastern New York at intervals from 1871 to the close of the season of 1886." The results of these investigations are continued in a number of papers in the *American Journal of Science*, from 1871 to 1888. Among the more important of them are the following, viz.: "What is true Taconic?" "Green Mountain Geology: on the quartzite" in 1872; "On the Quartzite, Limestone and asso-

ciated rocks of the vicinity of Great Barrington, Berkshire Co., Mass.," 1872–3; "An account of the discoveries in Vermont geology of the Rev. Augustus Wing; the relations of the geology of Vermont to that of Berkshire," 1877; "The Hudson River age of the Taconic Schists," 1879; "The geological relations of the Limestone belts of Westchester Co., New York," 1880–81; "On the Southward ending of a great synclinal in the Taconic Range," and "The Corlandt and Stony Point Hornblendic and Augitic rocks" in 1884; "Taconic rocks and stratigraphy," 1885, 1886 and 1887; "Lower Silurian fossils from a limestone of the original Taconic of Emmons," 1886; and the final paper of the series, "A brief history of Taconic ideas," in 1888. In addition to the above are "Two atlases, one of Berkshire Co., Mass., and the other of Westchester Co., New York, having on the back the title 'Taconic Rocks,' containing my [his] notes made in the geological survey of these regions," which were specifically bequeathed by his will to the Library of Yale College.

The solution of the problems was not alone Dana's work: the fossils discovered by Wing, Billings, Dale, Dwight, Ford, Bishop, Walcott and others were the evidences which finally redistributed the various members of Emmons' system into their proper places in the standard systems of the Palæozoic already defined. But as we look back over the battle and trace its progress, it is evident that the energy and thoroughness with which Professor Dana attacked the problems, if he did not do all the work, availed much in inspiring and directing the work of others; the bearings and importance of whose discoveries he was often quicker to discern than the discoverers themselves, and always gave full credit to whomsoever it was due. The final paper, "A brief history of Taconic ideas," is an admirable example of the calm judicial spirit with which he was accustomed to rise above all personal prejudices and individual opinions and to define scientific facts as they are.

Two other problems which grew out of the investigations already mentioned were, the interpretation of the partially metamorphosed rocks of the Connecticut Valley, and that of the

greenish schists on the western border of the Triassic in southern Connecticut.

Two papers were written upon the first subject, viz.: "On the rocks of the Helderberg era, in the valley of the Connecticut," 1873, and "The Helderberg formation of Bernardston, Mass., and Vernon, Vermont," 1877. The fuller elaboration of the stratigraphy and of the fossil contents were made by Professor B. K. Emerson of the Massachusetts survey. The other problem, about which the paper on "The 'chloritic formation' on the western border of the New Haven region," in 1876, and remarks in the "Geology of the New Haven region," 1870, opened the discussion, was not satisfactorily finished at the time of his death. It involves questions in metamorphism which call for petrographical as well as geological investigation, and whose solution must be left for other workers.

The preparation of the *Manual of Geology* was perhaps the greatest of his contributions to geology; of its value every geologist of America knows. It has done more to unify and codify American geology than any other work, and until very recent years, if we may judge from their literary quotations, foreign geologists have made Dana's *Manual* their chief source of information regarding the geology of America. It has always been characterized by that accuracy, and that fullness of details collected with a rare selective judgment, which has made it for every worker an indispensable handbook. In the last edition, which was finished but a few months before his death, he has combined the results of personal revision by the active workers in the more recently explored fields, with his own full knowledge of the current literature, to make it a complete account of the state of the science at the time of its publication.

In the breadth and richness of his knowledge an equal to Professor Dana is not likely to arise. For the thoroughness and industry which he applied to all his investigations, the fairness with which he treated all with whom he could not agree, the kindness and consideration he showed to all, and the unswerving devotion to the truth, James Dwight Dana will be long remem-

bered by all students of science. His geological contributions to American geology constitute such a fundamental part of our knowledge that so long as the science endures he cannot be forgotten.

HENRY SHALER WILLIAMS.

NEW HAVEN, 1895.